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16. ABSTRACT

Rapid infiltration treatment performance of three infiltration basins receiving primary treated municipal wastewater is evaluated for optimum total nitrogen control using a series of manual operational techniques and by remote control computer operation of a sprinkler system. Three types of loading sequences were used: flood loading every three and one-half days, flooding daily and sprinkler system loading based on soil moisture sensors and computer analysis and control. The influent and effluent quality variations were increased substantially compared with previous studies. Under optimum conditions, sustained removals of total nitrogen above 75% were achieved with values for individual weeks in the mid-80% range. Nitrogen removals were somewhat less for the automated sprinkler loaded system with a maximum four-week average of 65%.

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RAPID INFILTRATION WASTEWATER TREATMENT FOR SMALL COMMUNITIES

E. R. Bennett and L. E. Leach

INTRODUCTION

The high rate land treatment process utilizing rapid infiltration beds is well suited for use with small towns or isolated developments. It is an economically attractive, low energy consuming process providing a high degree of pollutant removal for wastewaters. When rapid infiltration beds are designed with direct discharge to the groundwater, nitrogen removal through soil adsorption, biological nitrification and denitrification becomes one of the key parameters in the design and operation of the process. In the earlier studies (1,2) at the same site as this research, it was found that nearly complete ammonia conversion to nitrate was accomplished when applying either primary or secondary effluent but that the removal of nitrogen from the wastewater by denitrification was relatively low, in the range of fifteen percent. Evaluations have been made on several rapid infiltration sites located in different regions of the country and the results have been reported in the literature. In general, nitrogen removals in the range of thirty to seventy percent have been experienced.

This research was focused on evaluation of the treatment efficiencies for biochemical oxygen demand (BOD), total organic carbon (TOC), suspended solids, coliform bacteria and phosphorus under a range of operating conditions that produced optimum removals of nitrogen on a concurrent basis.

FACILITIES

The rapid infiltration system utilized in this field investigation was located on the site of the 75th Street wastewater treatment plant in Boulder, Colorado. The 75th Street plant is a trickling filter plant situated on the south bank of Boulder Creek. Construction of the rapid infiltration site was accomplished in the spring of 1976.

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The site consisted of three basins, which were designated one, two, and three moving from south to north. The configuration of the beds is shown in Figure 1. The earth materials in the beds were approximately three meters (10 ft) deep and the base material was an impermeable shale strata. Earth berms, approximately 0.8 meters (2.5 ft) high, separated the basins, while a clay dike surrounding the entire basin area isolated the system from groundwater interference.

The rapid infiltration site was located in the Piedmont section of Boulder County. These deposits were composed of loose sand, loose gravel, and clayey sand underlain by bedrock of oceanic origin. Each of the beds originally had approximately 75 cm (2.5 feet) of finer textured material at the surface overlying coarse sand and gravel in the lower portion of the system. Prior to this study, 60 cm (2 ft) of the finer material was removed from beds two and three so that 15 cm (0.5 ft) of finer textured materials remained. All of the beds had twelve or more percent clay and two and one-half percent or more organic matter in the surface layer.

Primary effluent wastewater was pumped through a 0.35 meter (14 in.) delivery pipe to the rapid infiltration site. Two methods of bed loading were used. From December, 1980 to January, 1983, the beds were flood loaded. During the summer of 1982, a fixed sprinkler distribution system was installed on beds two and three and this loading method was initiated in January of 1983. The system consisted of a network of 10 cm (4 in.) diameter aluminum irrigations pipes with risers installed at 6.2 meter (20 ft.) intervals. Rotating sprinkler nozzles were installed at the top of the risers with each nozzle having a 4.4 mm (11/64 in.) orifice. There were 13 rotating nozzles per bed. The spray loading system was designed to operate at a gage pressure of 2585 mm of Hg (50 psi). The pipeline from the primary clarifier to the beds was modified so that it passed through a trailer in an inverted "U" shaped loop. A tee was installed in the pipe so that the flow could be directed to the flood loading of the beds or it could be diverted to a separate pump and valving system that would allow the spray systems to be operated.

The primary purpose of the sprinkler system was to use a computer operated loading pattern based on sensing instruments at the site to control the moisture content of the soil in order to optimize the conditions for the nitrifying and denitrifying bacteria in the soil. Each bed had three sets of electrodes at 5 cm and 30 cm depths that measured soil temperature. Three moisture content probes were also installed in each bed at the 5 cm depth. The temperature and moisture content data were measured on computer command and sent by telephone to the control computer located in the Robert S. Kerr, Environmental Research Laboratory in Ada, Oklahoma. The computer was programmed to make an analysis of the data and relay a signal back to the control trailer at the Boulder site if the spray pumps were to be turned on based on the sensing of soil moisture contents. The system

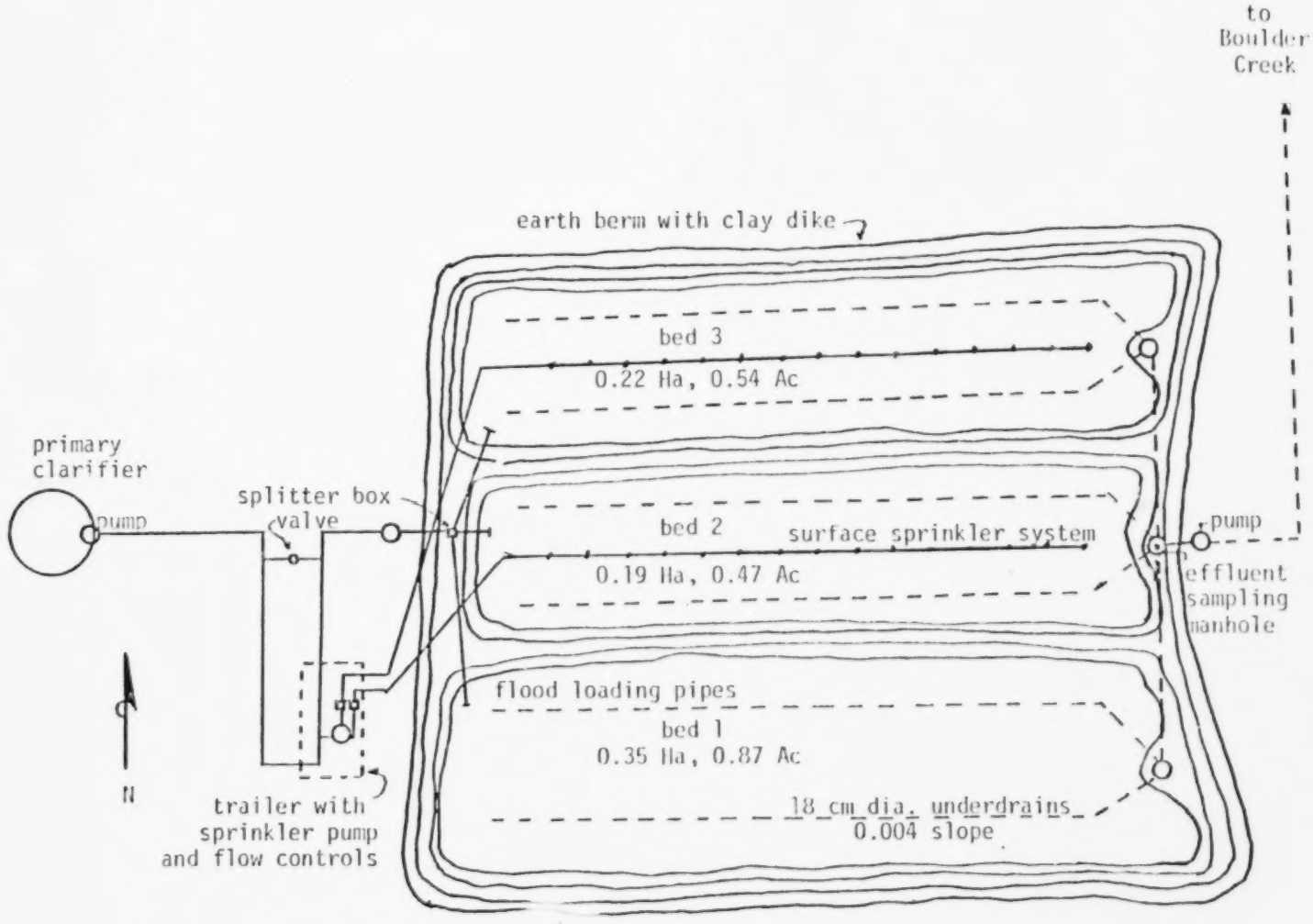

Figure 1. The rapid infiltration system layout.

was programmed to not operate when the temperature was below -5°C or when the wind velocity measured at the site exceeded 56 Km/hr (35 m.p.h.). It was also possible to operate the sprinkler system manually at the site if desired.

After the wastewater passed through the soil materials in the beds, it was collected in an underdrain system consisting of two perforated 18 cm (7 in) diameter pipes running the length of each bed at a soil depth of 2.5 to 3.2 meters (8 to 10 ft), just above the shale layer at the bottom of the beds. The line from each of the beds had V-notch weirs installed in the in the effluent sampling manhole for flow rate measurements.

For the first two years of the study, the influent pipe lead directly to an in-line, totalizing, propeller flow meter and then to a distribution splitter box. Lift plate gates were used to divert the flow to bed 1, bed 2 or bed 3 during flood loading. In the third year of the study, a section of the influent pipe was removed, reducers were attached to each end of the remaining pipe and a pipe was installed in a 'U' shape, through the control trailer and back to the original pipe. The pipe had a tee connection to a 7 cm (3 in) diameter pipe which lead to a shut-off valve and the sprinkler pump. The pump discharge branched into two pipes each having a pressure actuated, rate of flow controller. Each of the two pipes exiting the control trailer was connected to a 10 cm (4 in) diameter aluminum irrigation pipe that lead to the west edge of beds 2 and 3 and continued down the center of the beds to the east end. The ends of the irrigation pipes were capped and 2 cm (0.75 in) diameter risers were installed at 6.2 meter (20 ft) intervals. Rotating sprinkler heads at the top of the risers had a application radius of approximately 12.3 meters (40 ft).

OPERATION

Two effluent samples, acidified and unacidified, were taken at the outlet streams of the individual beds in the effluent manhole on intervals of 3, 7, 10, 24, 34, 48 and 72 hours after loading was initiated and effluent flows were measured at each time. The acidified aliquots were used for the analysis of ammonia, total Kjeldahl nitrogen, nitrate, phosphorus and TOC. The unacidified volumes, taken at effluent peak flow, were for pH, BOD and suspended solids analyses. Special grab samples of influent and effluent flows were obtained using sterilized bottles for the coliform tests and using nitric acid acidified bottles for the calcium, magnesiun and sodium series. All chemical analyses were accomplished using methods from Standard Methods for the Examination of Water and Wastewater(3), or Methods for Chemical Analysis of Water and Wastes(4), using blanks and spikes for quality control.

Nitrogen removal involved biological nitrification and denitrification processes and for this reason, wastewater treatment plant primary effluent was used as the influent to the process to provide an adequate carbon source for the biological growth. Another reason for the use of primary effluent was to demonstrate that rapid infiltration was an effective and reliable means of achieving high removal efficiencies for BOD, suspended solids, prosphorus and other pollutional parameters while operating in a mode intended for optimum nitrogen removals.

The research was conducted as a field study using several different loading rates, loading-resting patterns and two application techniques; flood loading and sprinkler loading. At times, the combination of these parameters did not result in optimum conditions. For this reason, the time-concentra- tion curves are presented to illustrate the effect of the variables. The average removal percentages are used to summarize the treatment achieved by the rapid infiltration process and values for the best four week period during the study are shown and give an indication of the performance that could be expected for a system operating continuously at near optimum conditions. Individual weekly removal percentages displayed some degree of variability and this was due to the changing nature of the pollutional strength of the influent stream, which is typical of a field study. For this reason, longer term four week trends in removal percentages are more significant.

During the study, the Boulder wastewater treatment plant was involved in a major construction project. Relocation of the rapid infiltration influent pipe was necessary and this caused some down time for the beds that was not a planned part of the research. The inactive period for beds 2 and 3 during weeks 118-135 was caused by the construction.

Three different modes of wastewater application were used during the study. Initially, the beds had a target value for flood loaded of approximately 40 cm (16 in.) of primary effluent on three and one-half day intervals. This pattern was followed for the first 78 weeks of the study encompassing the period from December of 1980 through March of 1982. The second loading sequence, which involved only bed 1, utilized a lower loading rate of approximately 5 cm (2 in) of flooding application each day. This was used from April, 1982 through February of 1983. The third mode, the sprinkler distribution system was ready for use on beds 2 and 3 after January, 1983, and it was necessary to discontinue the research operation of bed 1 because the overflow of the sprinkler pumping system was directed to bed 1 and made it impossible to maintain a consistant and measured loading amount. The sprinkler system operated from January through December of 1983, although it was interrupted from March through June due to the construction in the treatment plant. The average loading rates and loading patterns are summarized in Table 1. The loading rate for

the 3.5 day pattern averaged 123 ft/yr. based on the weeks that loading actually occurred. Resting of the beds was necessary and this occupied 28 percent of the weeks of this portion of the study. The overall average loading rate over time including resting periods is given in the table. No intentional resting periods were utilized with the 1 day or sprinkler system patterns. Downtime periods caused by construction in the wastewater treatment plant were not included in the calculation of loading rates.

TABLE 1. LOADING DEPTHS

Operating Mode		1 flood (3 1/2 day)	2 flood (1 day)	3 sprinkler
loading rate, inc. resting.	cm/d	7.42	4.67	3.84
	ft/yr	88.6	56	46
	gal/d-ft^2	1.8	1.15	0.95

RESULTS

The average concentrations for the rapid infiltration bed influents and effluents as well as removal percentages for the total period of each loading mode are given in Table 2. Some of the measured chemical constituents of the wastewater including pH, sodium and magnesium were essentially unchanged during the rapid infiltration process. The slight increase in calcium probably resulted from dissolving of calcium carbonate deposits in the bed material.

Coliform removals were significant, but relatively nigh concentrations remained in the process effluents. The results of this study show that the long term use of underdrained rapid infiltration beds may require disinfection of the effluent prior to discharge into a surface receiving water.

The values shown in Table 2 include periods of study when the variables tested were not at optimum. In order to judge a more optimized system performance, Table 3 has been constructed with a summary of the removal percentages for the important parameters shown and with the efficiencies resulting under the best condition studied based on four continuous weeks of operation. The first ten weeks of the study were not included in the selection of the best four weeks of operation because the beds had been rested for more than a year and this period of loading did not represent normal operation.

TABLE 2. AVERAGE CONSTITUENT CONCENTRATIONS AND REMOVALS

Constituent	Bed influent	Bed effluent	% rem.
Mode 1 (3 1/2 day)			
Nitrogen			
Ammonia-N	16.5 mg/l	6.5 mg/l	60
Nitrate-N	0.27 mg/l	1.85 mg/l	-
Organic-N	7.05 mg/l	0.85 mg/l	88
Total-N	23.82 mg/l	9.20 mg/l	61
T. Phosphorus-P	7.65 mg/l	1.33 mg/l	83
BOD-5	101 mg/l	8.8 mg/l	91
TOC	67.3 mg/l	10.2 mg/l	85
Suspended solids	51.2 mg/l	14.7 mg/l	71
Coliforms/100 ml			
Total	58.5×10^5	1.6×10^5	97
Fecal	13.4×10^5	0.65×10^5	95
pH	6.85	6.85	-
Calcium	41.6 mg/l	58.6 mg/l	-41
Magnesium	21.5 mg/l	21.5 mg/l	0
Sodium	56.6 mg/l	53.0 mg/l	6
Mode 2 (1 day)			
Nitrogen			
Ammonia-N	13.75 mg/l	3.23 mg/l	77
Nitrate-N	0.36 mg/l	4.58 mg/l	-
Organic-N	8.40 mg/l	1.06 mg/l	87
Total-N	22.51 mg/l	8.87 mg/l	61
T. Phosphorus-P	8.94 mg/l	0.53 mg/l	94
BOD-5	54.5 mg/l	3.8 mg/l	93
TOC	53.1 mg/l	6.7 mg/l	87
Suspended solids	53.9 mg/l	10.2 mg/l	81
Coliforms/100 ml			
Fecal	14.3×10^5	0.93×10^5	94
Mode 3 (sprinkler)			
Nitrogen			
Ammonia-N	17.85 mg/l	1.28 mg/l	93
Nitrate-N	0.13 mg/l	10.50 mg/l	-
Organic-N	6.76 mg/l	0.64 mg/l	91
Total-N	24.74 mg/l	12.42 mg/l	50
T. Phosphorus-P	7.13 mg/l	0.55 mg/l	92
BOD-5	80.4 mg/l	2.2 mg/l	97
TOC	54.8 mg/l	5.0 mg/l	91
Suspended solids	53.5 mg/l	6.0 mg/l	89

TABLE 3. COMPARISON OF THREE LOADING MODES
AVERAGE AND BEST 4-WEEK RESULTS

Operating Mode	1 flood (3 1/2 d) % rem.		2 flood (1 d) % rem.		3 sprinkler % rem.	
	ave.	4-week	ave.	4-week	ave.	4-week
Total Nitrogen	61	76	61	77	50	65
Total Phosphorus	83	87	94	97	92	98
BOD-5	91	91	93	96	97	99.5
TOC	85	85	87	91	91	96
Suspended solids	71	73	81	89	89	98

Nitrogen Removal

The use of rapid infiltration beds to remove nitrogen from wastewater involves the creation of aerobic conditions for nitrification and reducing conditions for denitrification simultaneously or sequentially in such a manner as to prevent pulses of ammonia or nitrate from being released in the effluent during any portion of the loading and infiltration cycle.(5,6,7) Ammonia volatilization was considered to be a minor factor.(8,9)

The beds had been standing idle for a year and they were scarified prior to any wastewater application. For the first ten weeks of loading, the influent percolated through the beds very rapidly. Infiltration rates were high (>50 cm/d) and the bed effluents were highly nitrified but with less than forty percent nitrogen removal. These results are shown as the beginning of the time-history curves of figures 2. The results shown in the figures are for bed 1 for the first 120 weeks of flood loading and for bed 2 with manually controlled sprinkler loading during weeks 109-117, followed by an inactive period caused by in-plant construction during weeks 118-135 and then for bed 2 with computer controlled loading for the remaining sprinkler loading period. The results of the other beds were similar. The top curve on each graph shows the loading rate as a function of the week of loading. The next curve shows the infiltration rate, and the third curve relates the total nitrogen concentration of the influent and effluent (solid dark lines) and the ammonia nitrogen concentration of the influent and effluent (lighter solid lines) and the nitrate nitrogen concentration of the effluent (dashed lines). Nitrites were included in the nitrate measurements. Organic nitrogen and influent nitrate nitrogen are not shown on the curves except that they are included in the total nitrogen values. The bottom curves show the percent removal of total nitrogen.

Soon after the fifteenth week of loading, the infiltration rate dropped rapidly with each loading. This was caused by a build up of a solids mat on the surface of the beds. The mat consisted of solids

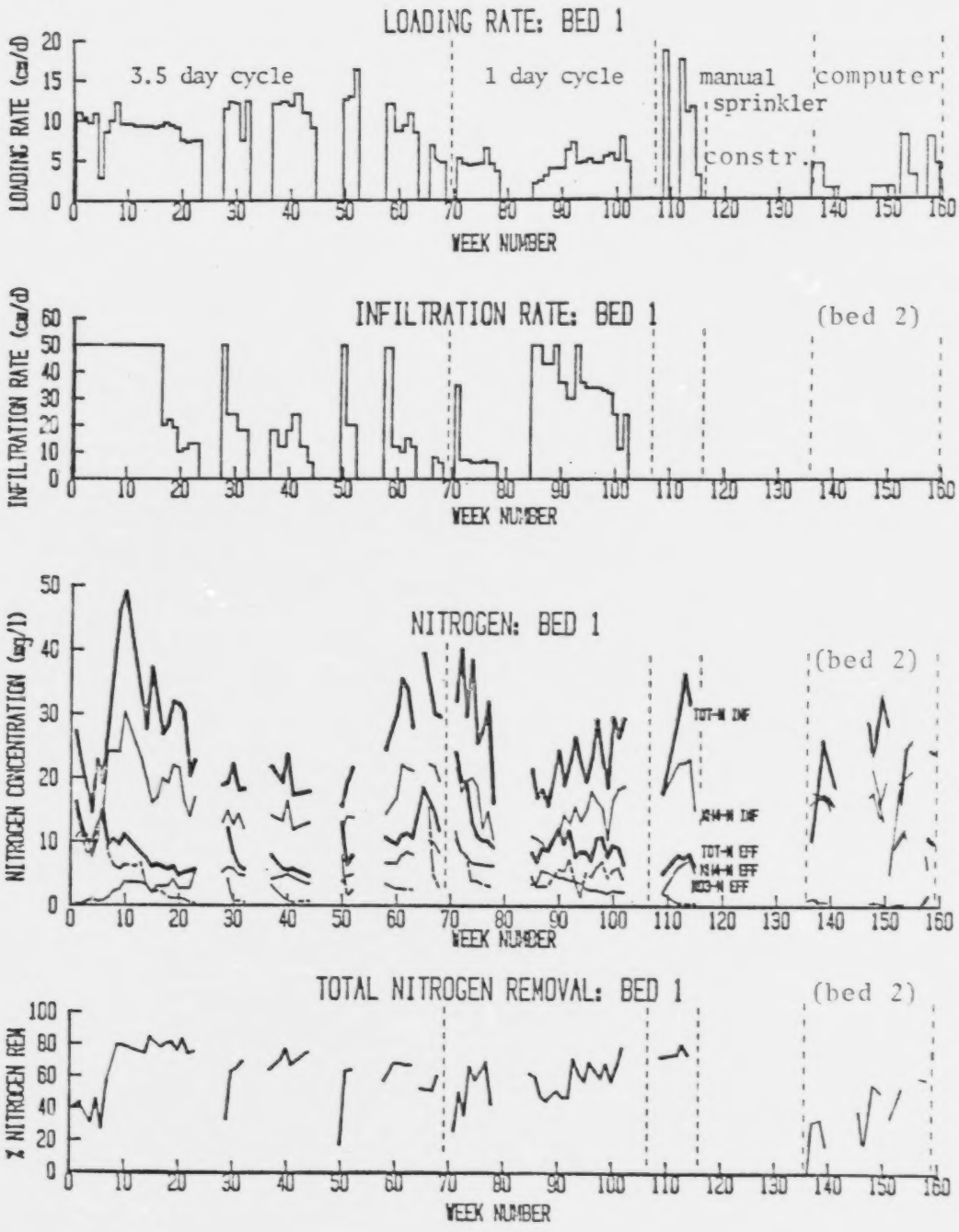

Figure 2. Nitrogen analysis for bed 1.

strained from the wastewater during the infiltration periods. The reduced infiltration rate caused the beds to be flooded over for a large portion of the three and one-half days between loadings. When the infiltration rate dropped below 20 cm/day (5 gpd/ft^2), the beds were flooded over continuously between loadings. As soon as this happened, the nitrate level in the effluent dropped and the ammonia concentration began to increase. The beds were rested and scarified after 23 weeks of loading. At that time the nitrogen removal was still high, averaging better than seventy percent, but the water was on the verge of flowing over the top of the side berms of the beds near the end of each loading period.

After resting and scarification, a nitrate flush occurred with the first loading. With further loadings, the infiltration rate decreased and the beds became flooded over again and the nitrogen removal rate was back into the seventy percent range. This pattern was continued using shorter periods between restings until the sixty-eighth week of the study. After the third loading sequence, the nitrate flush was nearly eliminated by using very light scarification. It was obvious from the data, that the ammonia level in the effluent was continually rising and the total nitrogen removal percentage was declining. Beds 2 and 3 were removed from the loading sequence so that the sprinkler system could be installed and bed 1 was loaded daily at a rate in the range of 5 cm (2 in.) per day. It can be seen from the curves that the ammonia level in the effluent decreased from week 71 to week 102 and the removal percentage increased. Beginning with week 136, the computer monitored sprinkler system was operational on beds 2 and 3. In order to prevent an overpressure in the influent pipe from the pump at the primary clarifier, it was necessary to allow an overflow stream to flood bed 1 whenever the other two beds were sprinkling. The overflow produced an unregulated flow on bed 1 and it was not monitored after week 115. Several different soil moisture control points were tried with each sequence showing improved removal but optimum steady state operation could not be obtained prior to the end of the field testing at week 158.

The initial loading rate of 37.6 meters/year (123.4 ft./yr.) producing a total nitrogen loading of 24.5 Kg/Ha-d (21.5 lb/ac-d) caused an overloading of the system resulting in continued increase in ammonia leakage into the effluent. When the loading was reduced to 17.0 meters/year (55.8 ft./yr.) with a total nitrogen loading of 11.1 Kg/Ha-d (9.9 lb/ac-d) beginning with week 71, the ammonia leakage showed a steady decline.

The removal of nitrate was accomplished by maintaining flooded over conditions on the basins. This was done for periods of more than a month without adversely affecting the total nitrogen concentration in the effluent. The low infiltration rates that resulted from the formation of solids mats on the bed surfaces were

necessary for the denitrification reaction to occur. The only times when poor nitrogen removals were observed were immediately after resting periods with scarification for the first three loading sequences when nitrates were released from the system due to the fact that it took several loadings to reduce the infiltration rate and establish reducing conditions. The operation with continuously saturated bed surface conditions was possible due to the field layout and the soil profile. It was possible for air to enter the lower, coarse strata of the beds from the sides and from the underdrain system.

The major factor affecting the effluent nitrogen concentration appears to be the nitrogen mass loading rate with respect to the soil cation exchange capacity. The cation exchange capacity is usually greater for soils of higher organic content. The cation exchange capacity for the upper layer of soil in the beds of this study ranged from 15 to 24. The coarse materials in the lower portions of the beds had measured values in the range of 2 to 3. Soil organic matter, including that disked in during scarification provides the energy source for the denitrifying bacteria and this may be an important source along with the BOD of the wastewater being treated.

Phosphorus Removal

Phosphorus removal from wastewater was evaluated in conjunction with the operating conditions needed for nitrogen removal. Land treatment of phosphorus involves the two sequential reactions of adsorption of the phosphate ion and precipitation of a solid that is retained in the soil matrix.(10,11) The precipitation usually appears to be the rate limiting step. When a system is overloaded, the rate of precipitation becomes inadequate to continually renew the sites for the adsorption reaction, and phosphorus leakage occurs in the process effluent.

The phosphorus removals in this study are summarized in Figure 3. The lower curves in each of the figures shows that the treatment system was severly overloaded during the initial 32 weeks of the research. Long resting periods in the following weeks caused the system to completely recover by week 50. Lower loading rates and more frequent resting periods maintained efficient phosphorus removals for the remainder of the study.

Three periods were selected from the data array (weeks 15-19, 74-78 and 92-96) as steady state condition for the points (squares) in Figure 4. A line was constructed through the points to illustrate the removal capacity of the soil in this research. The reported results of other researchers have also been shown.(12-20) The curve illustrates that there was a very discernible maximum loading rate that gave high removals and there was very little tolerance for overloading. Analysis of the phosphorus removal curve of Figure 5,

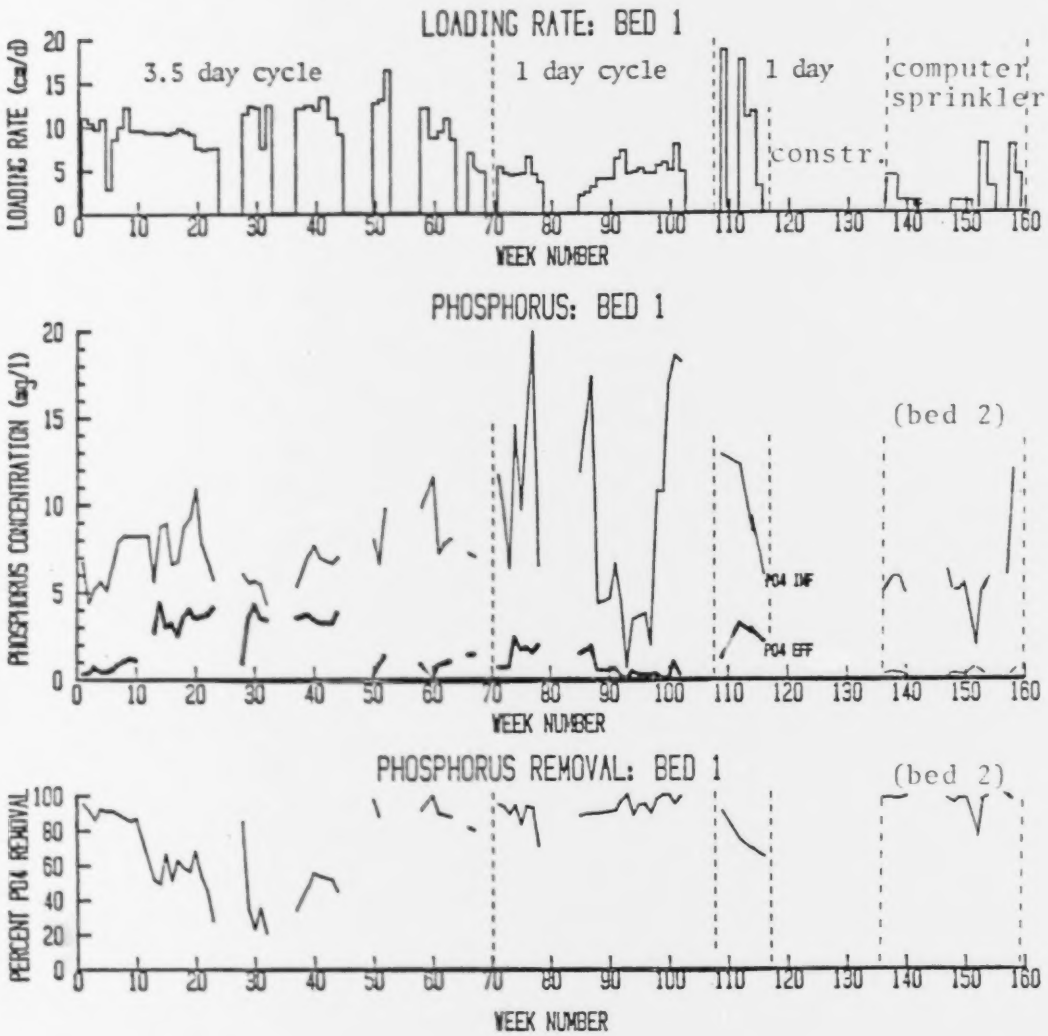

Figure 3. Phosphorus analysis for bed 1.

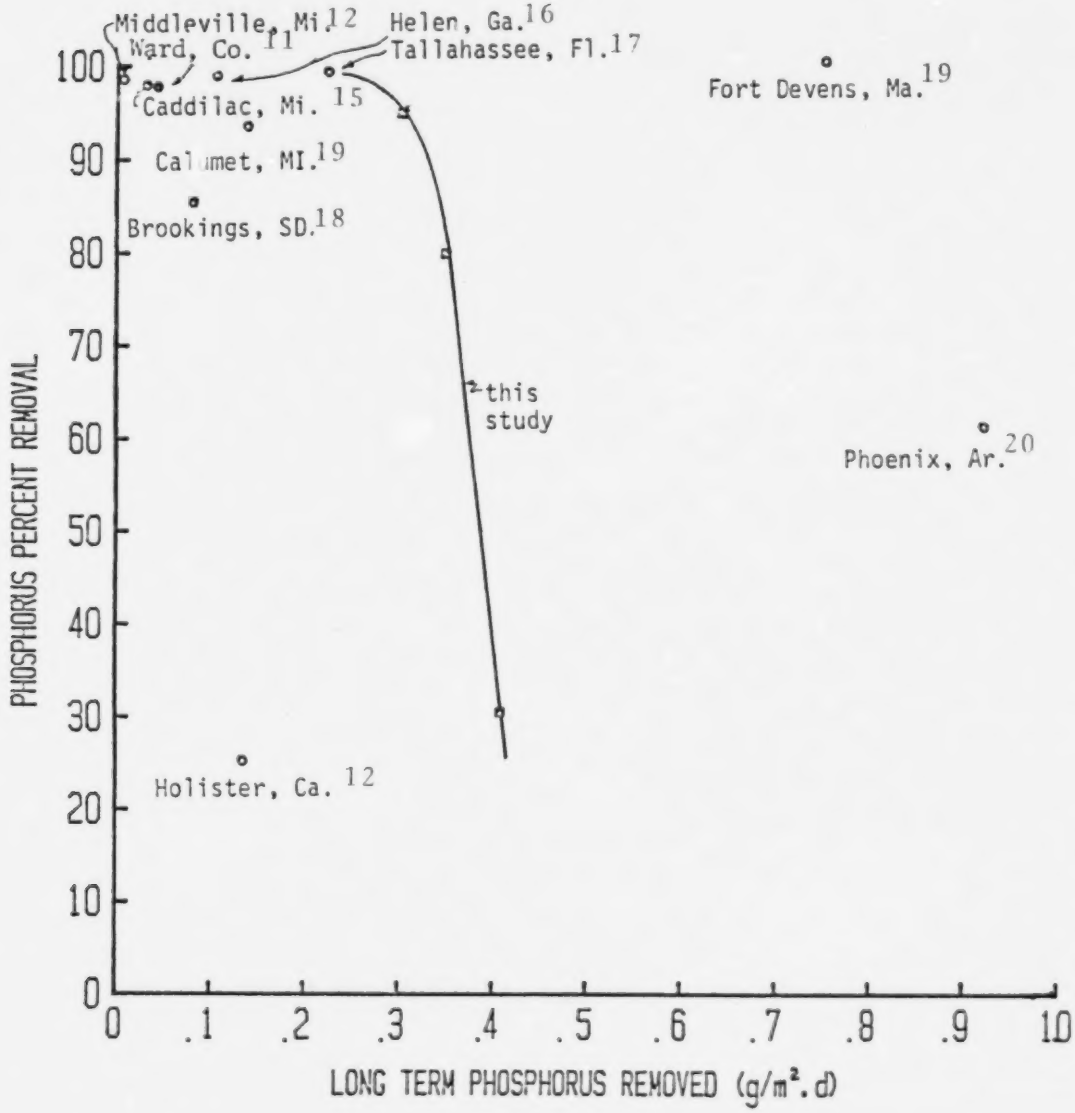

Figure 4. Phosphorus removal comparison with other studies.

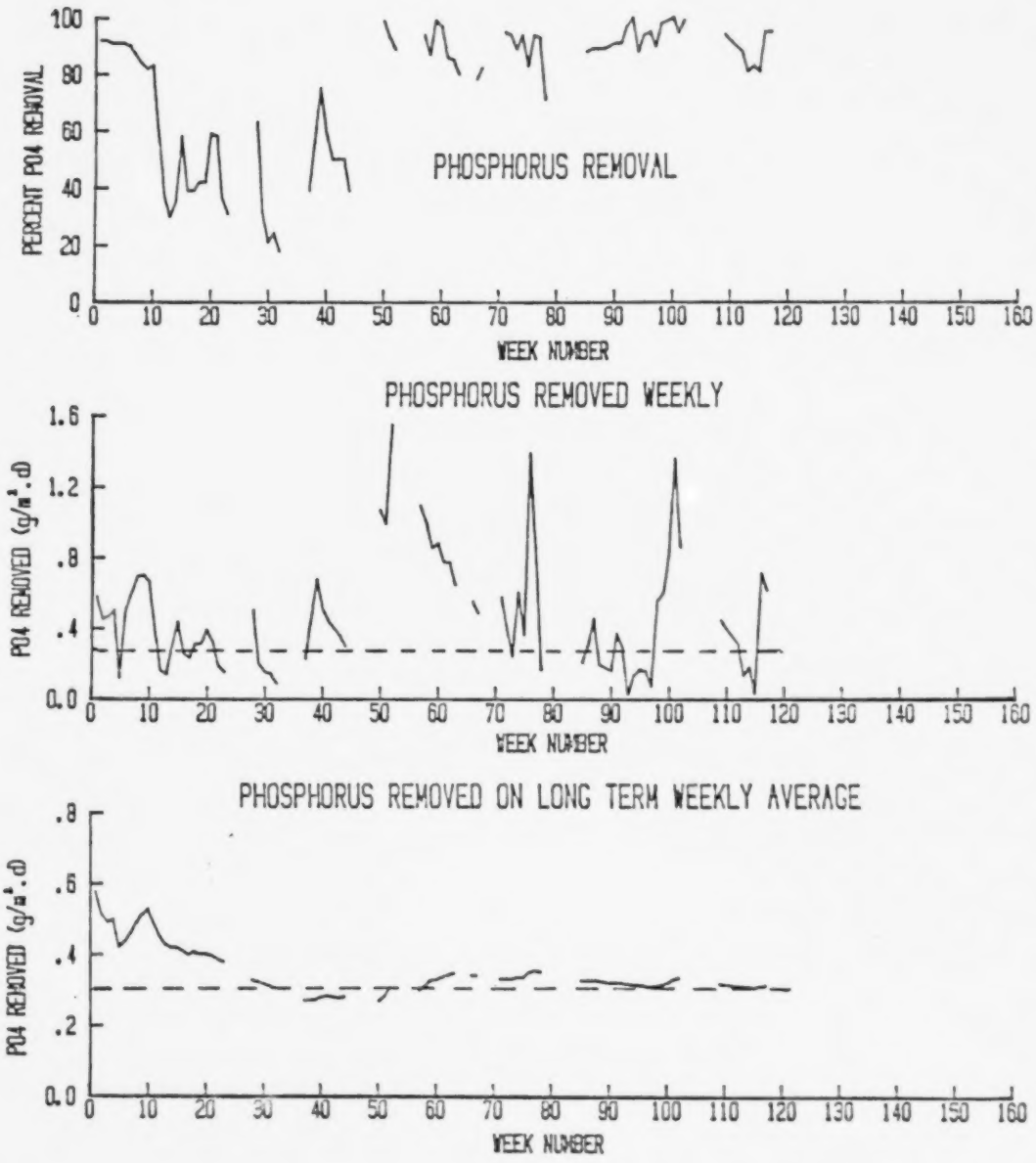

Figure 5. Effect of mass loading rate on phosphorus removal.

based on data for basin #1 during the period of the study showed that when the long term (total time from initiation of the study) or short term (weeks) phosphorus loading was greater than 0.3 g/m^2-d, the removal efficiency declined quite rapidly and when the phosphorus loading was reduced below that level the phosphorus removal improved. It was concluded that the value of 0.3 g/m^2-d represented the mineralization rate (phosphorus precipitation rate) for the soil of the beds used in this study. The other researchers points on Figure 4 show that the mineralization rate may have been quite different for the soils encountered in the different research projects and that the value may become less with many years of operation of a system.

BOD, TOC and Suspended Solids Removals

BOD and TOC gave similar patterns of high removal under all operating conditions for the rapid infiltration process. The most significant parameter affecting BOD removal was found to be the hydraulic loading rate. The graphical analysis for BOD for basin #1 is shown in Figure 6.

The effluent suspended solids concentrations were higher than would be expected for an earth filtration system. Suspended solids concentrations followed the same removal pattern as that of BOD except that the influent values were lower and the effluent values were two to three mg/l greater. Inspection of the underdrain system revealed extensive biological slime growth and this was concluded to be the source of the particulate matter in the effluent. For systems discharging directly to the ground water, this would not occur.

Operational Considerations

One of the major considerations in the use of rapid infiltration beds with primary effluent is the potential of odors near the site. Odors were not a problem during the period of this research. Most of the time during the study, ponded primary effluent was present on the beds. Natural surface aeration was sufficient to prevent septic conditions and the ponding did not cause offensive odors.

The highly nutriated soils in the beds produced voluminous weed growth on the surface of the beds during the warmer months. Weed cutting was a necessary part of the system maintenance program at this site for aesthetic reasons. This was done about every six weeks in the summer, during the period when the beds were rested. Excessive algae growth occurred when the ambient air temperature was above 33°C (90°F) for extended periods of time. This condition caused clogging of the solids mat on the beds accompanied by greatly reduced infiltration rates. When this condition became excessive, it was necessary to rest the beds. This tended to necessitate shorter more frequent periods between restings of the beds in the summer than in the winter months.

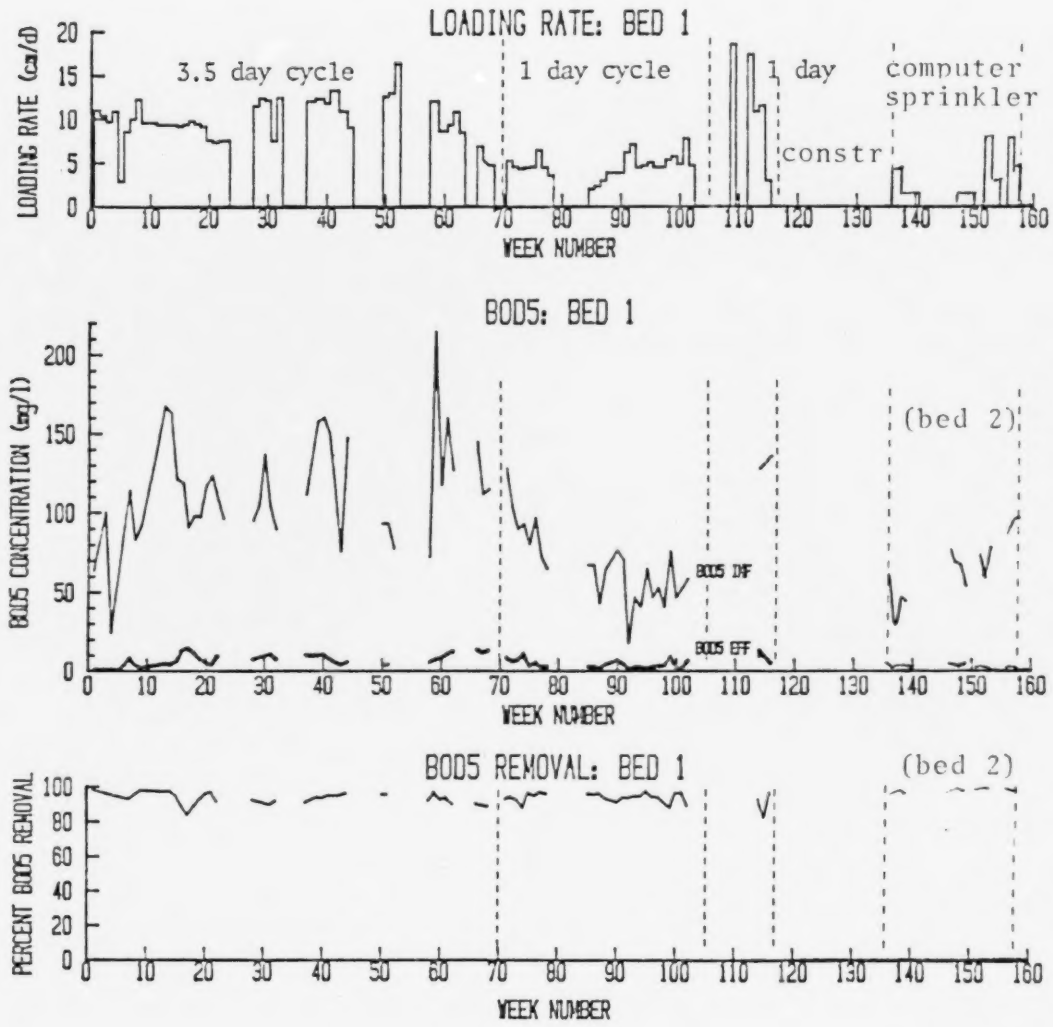

Figure 6. BOD analysis for bed 1

Cold weather conditions had very little effect on the operation of the flood loaded beds. Temperatures as low as -23°C (-27°F) were encountered for short periods of time. Under the worst conditions, an ice layer several inches thick was formed on the beds and this seemed to have little effect on the overall functioning of the system. Problems were encountered with the sprinkler system during severe winter conditions. The system experienced operating problems when the ambient air temperature went below freezing. Although the wastewater was warm enough to flow through the sprinkler nozzles in the normal fashion, some of the water would wet the outside of the sprinkler head housing. This water when frozen, would prevent the sprinkler head from turning and it would spray in the same position throughout the loading cycle.

The thin walled aluminum irrigation pipe was joined with connections having neopreme flap gaskets so that the pipe was water tight when pressurized and would drain the pipe at the joints when the pump was stopped between loadings. This prevented the freezing of the water within the pipe between loadings. It worked satisfactorily except when large snowstorms were encountered. The snow and ice surrounding the pipes would seal the joints causing the pipes to remain full of water and in some instances irrigation pipe rupture was encountered. Spray loading systems must be used with some care in winter weather and provisions must be made for cold periods when the system cannot be operated.

CONCLUSIONS

Rapid infiltration is a highly reliable process utilizing little mechanical equipment and therefore the energy and maintenance costs are low, especially when the flood loading mode is used. The system can be designed to discharge directly to groundwater or to a stream through underdrain collection pipes, such as used in this research. In either arrangement, rapid infiltration provides pollutant removals similar to those of advanced wastewater treatment.

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ABSTRACT

A research field study was conducted by the University of Colorado and the R. S. Kerr Laboratory of the EPA to evaluate the pollutant removal capabilities of the rapid infiltration process. One of the primary objectives was to obtain optimum nitrogen removal using this process and to evaluate the efficacy of removal of other pollutional constituents under the operational conditions necessary for enhanced nitrogen removal.

The rapid infiltration field site consisted of three basins with surface areas of 0.35, 0.19 and 0.22 hectares (0.87, 0.47 and 0.54 acres). Primary effluent from the City of Boulder wastewater treatment plant was applied to the basins utilizing hydraulic loading rates ranging from 4.4 to 76 meters/year (15 to 250 ft./yr.). Three types of loading sequences were used; flood loading every three and one-half days, flood loading daily, and sprinkler system loading based on soil moisture sensors and computer analysis and control. The influent and effluent quality variations were measured over a three year period and the performance of the system was related to the operational parameters. The quality parameters utilized were nitrogen (total, organic, Kjeldahl, ammonia and nitrite/nitrate), biochemical oxygen demand, total organic carbon, suspended solids, total and fecal coliforms, phosphorus and pH.

Under optimum conditions, sustained removals of wastewater nitrogen forms above seventy-five percent were achieved with values for individual weeks in the mid eighty percent range. Increased denitrification resulted from maintaining saturated soil conditions for long periods, using low infiltration rates and reduced hydraulic loadings. The removal of phosphates was shown to be directly related to a critical phosphorus mass loading of 3.0 Kg/Ha-d (0.3 gm/m^2-d) that represented the mineralization rate for the soil chemistry of the field system. Sustained removals greater than ninety-five percent were achieved. BOD and TOC removals were high throughout the study with most BOD values above ninety percent.